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Discussion on "Measuring energy efficiency in urban water systems using a mechanistic approach" by Leon F. Gay and Sunil K. Sinha

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Corresponding Author:	Enrique Cabrera Jr. ITA - Universitat Politecnica de Valencia Valencia, SPAIN
Corresponding Author E-Mail:	qcabrera@ita.upv.es
Order of Authors:	Enrique Cabrera Jr.
	Enrique Cabrera
	Vicent Espert
	Miguel Angel Pardo

Dr. Enrique Cabrera Rochera, MSc.
ITA – Universitat Politecnica de Valencia
Camino de Vera s/n – Edificio 5C
46022 Valencia (Spain)

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To whom it may concern:

Please find enclosed a discussion on

"Measuring energy efficiency in urban water systems using a mechanistic approach" by Leon F. Gay, S.M. ASCE and Sunil K. Sinha.

Journal of Infrastructure Systems, Vol. 18, No. 2, June 1, 2012, pp. 139-145
D.O.I. 10.1061/(ASCE)IS.1943-555X0000072.

Sincerely,

Enrique Cabrera

Discussion on "Measuring energy efficiency in urban water systems using a mechanistic approach" by Leon F. Gay and Sunil K. Sinha

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Enrique Cabrera Jr.[1]; Enrique Cabrera, M. ASCE[2]; Vicent Espert[3]; and Miguel Angel Pardo[4]

The original paper tackles a subject of great interest and proposes an indicator to quantify the energetic efficiency of the raw water production phase in urban water supply, the *Thermodinamic score (TS).* Additionally, the paper announces additional indicators for other system phases such as the distribution network.

Increasing the efficiency in the use of water and energy in water services is a key issue as demonstrated by a good number of papers on the topic published by different ASCE Journals. Following the principle that you can't manage what can't measure, a widespread strategy is to develop new metrics and performance indicators to quantify the potential improvements and identify the key factors to increase the efficiency.

The discussed paper contributes with a case study in which the proposed indicator is applied to eight different water utilities in Virginia. In all of them (with the exception of two gravity fed systems in which the proposed indicator cannot be applied) the potential found for improvement is quite significant. Regardless of the adequacy of the proposed indicator (which is the subject of this discussion) the truth is that the paper succeeds in raising the awareness of the significant potential energy savings for the systems under study.

Nevertheless, the proposed metric does not seem an adequate choice in the opinion of the discussers. Even the authors, in a sincere analysis of their work, are aware of its limitations. Quoting from their conclusions: "*Because the thermodynamic is conditional on system characteristics and depends on the $E_{min/}E_{actual}$ ratio, the score might indicate decreased energy efficiency after some major system changes that in fact increased energy efficiency. For example, capital improvement projects may have this undesirable effect on the thermodynamic score. This might be a*

[1] Associate Professor. ITA – Universitat Politecnica de Valencia. Apdo 22012. Valencia (Spain). Corresponding autor. E-mail: qcabrera@ita.upv.es
[2] Professor. ITA – Universitat Politecnica de Valencia. Apdo 22012. Valencia (Spain).. E-mail: ecabrera@ita.upv.es
[3] Professor. ITA – Universitat Politecnica de Valencia. Apdo 22012. Valencia (Spain).. E-mail: vespert@ita.upv.es
[4] Assistant Professor, INGHA, Dept. de Ingeniería de la construcción, Obras públicas e Infraestructuras, Univ. of Alicante, San Vicente del Raspeig, PO BOX 99, 03080, Alicante, Spain. Email: mpardo@ua.es

significant disadvantage of the thermodynamic score. Users of the score must be aware of such limitation". This undesirable behavior of the indicator spurred the interest of the discussers originating the present discussion.

As a consequence this discussion will focus on additional reasons that suggest a better option exists to the proposed metric and the causes of its unexpected behavior. Additionally, an alternative indicators is proposed which represents the efficiency in the energy use and is not affected by system changes and capital improvement projects.

Discussion on the proposed indicator

Performance metrics or indicators are now widely used in the water industry. In the past decade several international efforts took place to provide both a wide selection of key performance indicators (kpi) to measure water services performance and consistent performance assessment frameworks. The system defined by the International Water Association (Alegre et al., 2006) is widely recognized as an industry standard and its main principles were adopted in the ISO 24510, 24511 and 24512 standards for the management and assessment of water and wastewater services (ISO 2007, a, b and c).

The characteristics of a performance indicator are clearly defined in all these references from IWA and ISO. Quoting some of the key characteristics of performance indicators from any of the preceding documents,

"*each performance indicator should:*

(...)

- *be as universal as possible and provide a measure which is independent from the particular conditions of the utility,*
- *be simple and easy to understand,*
- *be objective and avoid any personal or subjective appraisal."*

In the discussers' opinion, the performance indicator as well as the variables (factors) used to calculate it present several problems or inconsistencies.

1. The choice for numerator and denominator seem strange. The proposed form for the TS shows the minimum energy as a numerator and the actual energy as the denominator. A more traditional option would be to invert the concepts, showing what is possible as a denominator and the actual performance as the numerator. This would lead to a much easier interpretation in which the resulting percentage indicates the factor by which the used energy exceeds the ideal situation.

   The intention of the authors is clear, designing a metric that yields a score from 0 to 100. And although it is certainly arguable which one is a better choice, we believe that 27,32 is much more intuitive as a result (showing that the energy used is almost 30 times higher than needed) than the Thermodynamic Score of 3,66% shown for WTP5.

2. The definition of E_{ideal} as "the minimum energy calculated under ideal conditions" does not seem entirely appropriate. E_{ideal} is the result of adding the static head and the friction loss. While the first component is clearly context determined and cannot be altered (thus constituting a true "ideal" minimum energy required in the system) friction loss are dependent on several factors like pipe diameter and condition (roughness) and even flow rate, meaning that the magnitude of this variable is not fixed and constitutes, in our opinion, a poor reference value. In other words, friction loss heavily depends on engineering decisions (pipe and pump selection) and should not be included as part of a "minimum" or "ideal" reference variable. This is the main reason for the changes in value in TS underlined by the authors, and which contradicts one of the main indicator's requirements quoted above (being independent from the particular conditions of the utility).

   On the other hand, the minimum pressure (or energy) required by the system or by users is an external condition to the engineering problem (an external condition, often set by laws or regulations) and should be included in this minimum or unavoidable energy consumption term. With this definition, E_{ideal} becomes completely independent of changes (like aging or renovations) in the system.

$$E_{ideal} = static\ head + required\ pressure \tag{5}$$

3. The proposed change turns E_{ideal} into the perfect denominator. It becomes an external reference and contributes to conform to ideal indicator behavior. Consequently, the discussers propose to substitute E_{min} (discussed in the following point) by the re-defined E_{ideal}. Nevertheless, E_{actual} is still included in the final definition proposed.

4. In the discussed paper, E_{min} is one of the key terms in the Thermodynamic Score and includes both the useful energy and the energy loss (friction loss, inefficiencies in pumping and energy associated to water loss). The mixing of these two terms of different nature has already been discussed in (2) and why it is advised to replace it by a new denominator.

   However, the original definition of E_{min} does not seem adequate either. It includes what the authors define as "*the minimum energy use that is realistically achievable by the utility after considering real-world values for pumping efficiency, water delivery pressure, and water loss"*. The discussers believe that no such thing as standardized "real-world" values can be successfully used in a performance indicator. For instance, a recent work (Pérez Urrestarazu and Burt, 2012) explored the wire-to-water pumping efficiency of 15000 cases and found a great dispersion in values (ranging from 30% to 80%). It seems reasonable to think that a similar or even greater diversity may be found regarding water and friction loss.

   The inclusion of these real-world values is against another of the key characteristics of performance indicators quoted earlier ("be objective and avoid any personal or subjective appraisal"). In the proposed form, this arguable term determines the result of the indicator and therefore introduces subjectivity.

5. Finally, and on a more marginal note, the terminology used for the indicator does not seem adequate either. The authors define (even in the title) the approach used as "*mechanistic*" and, indeed, the indicator is obtained without using the thermal equations in fluid mechanics. Therefore, we believe that "Thermodynamic Score" is not the best choice for an indicator that seeks to portray the mechanical efficiency. Similarly, E_{ideal} seems a poor choice for a term including friction loss.

Alternative proposal

Understanding the nature of energy loss is key to implement actions aimed to improve the efficiency. Solutions are often specific and decoupled (an increased pumping efficiency will not improve water loss figures).

The discussers have developed (Cabrera et al., 2010) an energy audit for water distribution networks. The work includes the definition of two context information elements and five efficiency indicators. The TS indicator under discussion would be equivalent to the I_1 indicator (inverted) proposed then.

Its definition (equation 5) is the ratio between the energy E_{actual} (which the discussers called E_{input}, and represents the amount of energy present in the electric bill) and E_{ideal} as re-defined earlier. It is therefore a measure of the Excess of Supplied Energy (ESE)

$$ESE = \frac{E_{actual}}{E_{ideal}} \tag{5}$$

Both terms are related, and breaking down their components allows understanding the nature of each term:

$$E_{actual} = E_{ideal} + pump\ inefficiencies + friction\ energy\ losses + water\ energy\ losses + surplus\ pressure = E_{ideal} + E_{wasted} + \Delta E_{surplus} \tag{6}$$

Combining (5) and (6):

$$ESE = 1 + \frac{E_{wasted}}{E_{ideal}} + \frac{\Delta E_{surplus}}{E_{ideal}} = 1 + I_w + I_s \tag{7}$$

Equation 7 represents an elementary and quite intuitive analysis of the energy taking part in the process. It shows how the excess of energy delivered equals the sum of the wasted energy and the energy surplus delivered to the water (i.e. the additional pressure with respect to the minimum required value). Following this logic, the proposed inefficiency indicators (I_w and I_s) show how each fraction of excess energy (the wasted and the surplus) is used.

Furthermore, the I_w indicator can be broken down in three additional inefficiencies which characterize the process:

$$I_w = \frac{E_{wp} + E_{wf} + E_{wl}}{E_{ideal}} = I_{wp} + I_{wf} + I_{wl} \tag{8}$$

The value for these three indicators is easily obtained. The first one requires determining the wire-to-water efficiency, as shown by Pérez Urrestarazu and Burt (2012) which is a simple but necessary calculation.

The second one is also easy to calculate and, as a matter of fact, receives much of the attention in the paper under discussion that even contemplates its evolution with pipe aging.

The third indicator is the most complex of the three and is also solved by Cabrera et al. (2010).

Once all three inefficiencies have been calculated (Equation 8) the cost-benefit analysis of any improvement action can be assessed immediately.

Final remark

Developing better metrics for estimating the energy savings around the urban water cycle and, at the same time ensuring that efficiencies are evaluated on a level playing field is a crucial issue for the water industry. But these metrics must be reliable and coherent and withstand the test of time. To this purpose, the recommendations obtained after 15 years of work on indicators for water services should not be ignored.

Contributing to that goal is the main purpose of this discussion, and it is our belief that the suggested amendments provide significant improvements to the metric proposed by the authors to quantify the energy efficiency of raw water transport.

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Manuscript Authors: ENRIQUE CABRERA JR, E. CABRERA, V. ESPERT, M.A. PARDO

Corresponding Author Name and Address: ENRIQUE CABRERA JR. APDO 22012 - 46078 - VALENCIA (SPAIN)

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